A SCENARIO ANALYTICAL TRADE-OFFS AMONG AGRICULTURAL GROWTH GOALS AND SHIFTS IN LAND USE OF INDIA

NABHIRAJ ANNAPPA PATIL
Research Scholar, Dept. of Geography,
Sri Satya Sai University of Technology & Medical Sciences,
Sehore, Bhopal-Indore Road, MadhyaPradesh, India
Dr. Vinay Singh
Research Guide, Dept. of Geography,
Sri Satya Sai University of Technology & Medical Sciences,
Sehore, Bhopal Indore Road,Madhya Pradesh, India

ABSTRACT

India has the second largest population in the world and is characterized by a broad diversity in climate, topography, flora, fauna, land use, and socioeconomic conditions. To help ensure food security in the future, agricultural systems will have to respond to global change drivers such as population growth, changing dietary habits, and climate change. However, alterations of how food is produced in the future may conflict with other UN Sustainable Development Goals (SDGs), such as the protection of land resources and climate change mitigation. It is crucial for decision-makers to understand potential trade-offs between these goals to find a balance of human needs and environmental impacts. In this paper, we analyze pathways of agricultural productivity, land use, and land-cover changes in India until 2030 and their impacts on terrestrial biodiversity and carbon storage. The results show that in order to meet future food production demands, agricultural lands are likely to expand, and existing farmlands need to be intensified. However, both processes will result in biodiversity losses. At the same time, the projections reveal carbon stock increases due to intensification processes and decreases due to conversions of natural land into agriculture. On balance, we find that carbon stocks increase with the scenarios of future agricultural productivity as modeled here. In conclusion, we regard further agricultural intensification as a crucial element to help ensure food security and to slow down the expansion of cropland and pasture. At the same time, policies are required to implement this intensification in a way that minimizes biodiversity losses.

KEYWORDS: Ecological Dimensions, Urban Development, Economic Implications.

INTRODUCTION

By area, India is the world's seventh largest country along with a population of about 1.3 billion people in 2015 (FAO, 2017a; UN-Pop, 2017). India is characterized by an immense diversity in climate, topography, flora, fauna, land use, and socioeconomic conditions (FAO, 2017b). During the past 140 years, India has experienced remarkable land use and land-cover changes including deforestation, cropland changes, and urban expansion (Roy et al., 2015; Tian et al., 2014). Over half of the territory is used as cropland, making India one of the largest producing countries of agricultural commodities worldwide (FAO, 2017a; Teluguntla et al., 2015). In 2016, the agricultural sector comprised 23% of the total economy, as measured by the gross domestic product, and employed around 59% of the country's total labor force (FAO, 2017b). Two thirds of the Indian population lives in rural areas (World Bank, 2016) and, with a relatively high poverty rate, is home to one of the largest populations (175.7 million) living below the World Bank's poverty line of $1.90 a day (World Bank, 2018). India has experienced notable increases in agricultural productivity over the last decades (Chand &Parappurathu, 2012; Pingali, 2012). Nevertheless, there are still significant yield gaps for many crops across the countryside (Brahmanand et al., 2013; Sharma, 2016). The existence of yield gaps can be explained by many confounding factors, such as the prevalence of subsistence farming and poor access to chemical inputs, improved technology, and management techniques (Bhattacharyya et al., 2015; George, 2014; ICAR, 2015).

India's food production needs to be increased substantially in the coming decades due to an expected population growth up to more than 1.6 billion in 2050 (UN-Pop, 2017) along with changingdietary preferences like a higher demand for animal-sourced products (Alexandratos&Bruinsma, 2012). This is an extremely challenging issue. Currently, India provides food to 18% of the world's population but occupies only 2.4% of the world's total land area (Bhattacharyya et al., 2015; Teluguntla et al., 2015). Studies such as Mauser et al. (2015) see large potential in India for increasing agricultural productivity by improving management practices and adopting new crop varieties. To realize these improvements, further investments in research and development (R&D) in the agricultural sector are required. At the same time, possible negative environmental impacts due to agricultural intensification cannot be neglected (e.g., Ramankutty et al., 2018; Rockström et al., 2017; Springmann et al., 2018; Srivastava et al., 2016; Tilman et al., 2017; Tilman& Clark, 2014). India is still one of the richest nations in terms of biodiversity, and the remaining forest area (22% of the total area) represents a significant carbon stock that needs to be conserved as a means of climate change mitigation (Nadagoudar, 2016; Roy et al., 2015; Swaminathan&Bhavani, 2013; Tian et al., 2014). According to the IPCC (2014), India is likely to suffer from a higher frequency of extreme temperature and precipitation events. The cyclical monsoon system has been identified as one tipping element of the global climate system, which means that strong climate change might drastically change atmospheric circulation patterns globally (Lenton et al., 2008; Steffen et al., 2018). With such a systemic shift, there could be significant impacts on India's agricultural sector. Thus, one of the main challenges facing India today is to develop strategies to sustain and improve living conditions of a growing population, while continuing to satisfy shifting consumption patterns and limit negative environmental outcomes (Nadagoudar, 2016; Roy et al., 2015; Swaminathan&Bhavani, 2013; Tian et al., 2014).

The Sustainable Development Agenda of the United Nations (United Nations General Assembly, 2015) recognizes the negative impacts of food insecurity, biodiversity loss, and climate change on human development issues by including them as priorities in the Sustainable Development Goals (SDGs). While SDG 2 (Zero Hunger) addresses food security, SDG 15 (Life on Land) demands, among other things, the preservation of biodiversity and SDG 13 (Climate Action) focuses on climate adaptation and mitigation efforts. However, many scientific approaches that aim at informing policies to achieve the SDGs are sector-specific assessments and often disregard the interrelationships identified in multisectoral assessments (Obersteiner et al., 2016; Tagar et al., 2016). First attempts to systematically analyze interactions and trade- offs between SDGs were conducted by Pradhan et al. (2017) and Gao and Bryan (2017). Spatially explicit simulation models are useful tools to explore the dynamics of future agricultural development, related land use change, and resulting environmental impacts (Alexander et al., 2017; Li et al., 2017; Prestele et al., 2016). For India, Schaldach, Priess, et al. (2011) use a spatially explicit land use model to assess the effects of biofuel development on land use change. While numerous global studies that include India as a subregion tackle the effects of land use change on either biodiversity (e.g., Delzeit et al., 2017; Kok et al., 2018; Newbold et al., 2016) or carbon storage (e.g., Popp et al., 2014), only a few studies are available that address effects on both impact categories (e.g., Eitelberg et al., 2016; Molotoks et al., 2018). In this paper, we analyze a set of scenarios of future agricultural development in India and assess potential trade-offs between food production to prevent hunger (SDG 2), climate mitigation (SDG 13), and biodiversity (SDG 15). For our analysis we adapt and apply an integrated modeling framework that combines an economic model with different spatially explicit models. Since the UN Agenda defines 2030 as a target year to make substantial improvements in reaching the SDGs, we have chosen this year as the time horizon for the scenarios. In the following section the applied models and the scenario assumptions are described. This is followed by a section that describes our simulation results and a discussion of our main findings.

SCENARIOS AND ECONOMIC MODELING

For our analysis, we use four global scenarios (Table 1) that were developed as part of the CGIAR Global Futures and Strategic Foresight project, led by the International Food Policy Research Institute. The focus of that scenario exercise was to evaluate the effectiveness of different investment strategies in the agricultural sector with regard to food security under global change conditions up to the year 2050 (Rosegrant et al., 2017). All scenarios follow the Shared Socioeconomic Pathway 2 (SSP2) “middle of the road” assumptions on population and economic growth (Kriegler et al., 2014; Moss et al., 2010; van Vuuren et al., 2014). For this pathway, it is assumed that India's population will grow to more than 1.5 billion by the year 2030 while the economy is characterized by strong gross domestic product increases (Dellink et al., 2017; Samir & Lutz, 2017). In addition, the International Food Policy

Research Institute scenarios combine these drivers with assumptions about different investments in R&D in the agricultural sector across the CGIAR research portfolio. These measures are assumed to comprise investments in advanced breeding techniques, including further advances in genomics as well as in efforts to increase the efficiency of scientific institutions to achieve productivity gains (Rosegrant et al., 2017).

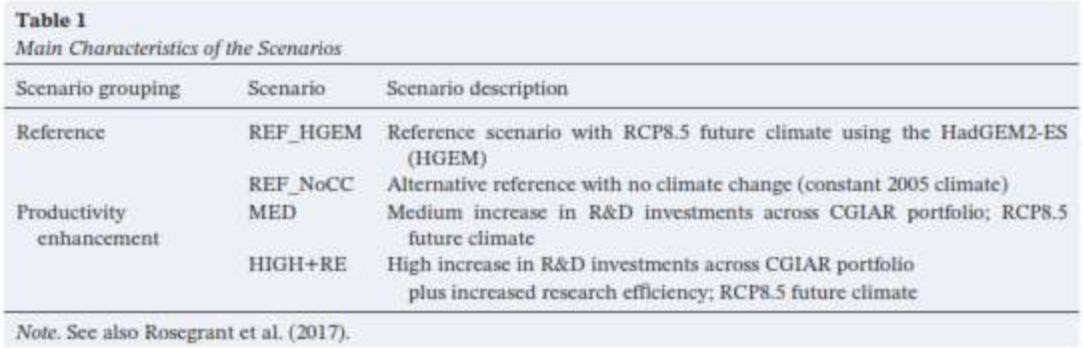

Table 1
Main Characteristics of the Scenarios

Scenario grouping	Scenario	Scenario description
Reference	REF_HGEM	Reference scenario with RCP8.5 future climate using the HadGEM2-ES (HGEM)
	REF_NoCC	Alternative reference with no climate change (constant 2005 climate)
Productivity enhancement	MED	Medium increase in R&D investments across CGIAR portfolio; RCP8.5 future climate
	HIGH+RE	High increase in R&D investments across CGIAR portfolio plus increased research efficiency; RCP8.5 future climate

Note. See also Rosegrant et al. (2017).

The first two scenarios serve as reference cases with R&D investments following current trends and therefore directly represent the SSP2 storyline. The REF_NoCC scenario uses constant climate conditions around the year 2005 while the REF_HGEM scenario assumes climate change according to a RCP8.5 climate scenario (van Vuuren et al., 2011). In addition, two investment scenarios are specified. The MED scenario assumes an intermediate level of additional R&D investments by CGIAR centers while the HIGH+RE scenario considers a high increase in CGIAR investment plus an increased CGIAR research efficiency. Both investment scenarios assume climate change according to a RCP8.5 climate scenario. The crop modeling component of the IMPACT model (DSSAT and MINK) translates the climate change scenarios into a clear signal of what the impact of average climate change trends will be on crop yields. In addition, for each scenario the R&D investments are translated into crop yield increases following a logistic adoption pathway, based on historical trends and using expert judgment from regional CGIAR centers regarding the potential of crop productivity development for each region modeled. Then, the four scenarios are simulated using the IMPACT model. The scenario development process is described in detail in Robinson et al. (2015) and Rosegrant et al. (2017). The effects of climate change (e.g., temperature and precipitation changes) were projected by the Hadley Centre Global Environment Model, version 2 (HadGEM2-ES (HGEM); Jones et al., 2011). We have chosen the RCP8.5 scenario and a reference case with 2005 climate conditions in order to investigate a broad corridor of potential climate change impacts on crop yields and to assess the robustness of the different investment strategies under climate change. As pointed out in section 2.1, country-level information that is passed from IMPACT to LandSHIFT includes crop and livestock production as well as the crop-specific yield changes in India.

LAND USE MODELING

The Land SHIFT model is used to calculate spatial and temporal land use change due to crop cultivation, grazing, and urbanization. It has been validated and tested for India in the context of biofuel assessments (Schaldach, Alcamo, et al., 2011; Schaldach, Priess et al., 2011). The model is based on the concept of land use systems (Turner et al.,

2007) and couples components that represent anthropogenic and environmental subsystems. Drivers of land use change are specified on the country-level, while the spatially distributed land use modeling is carried out on a regular grid. Cell-level information comprises land use type, human population density, landscape characteristics (e.g., terrain slope, potential yields, road infrastructure), and land use restrictions (e.g. protected areas). Table S2 gives an overview of the data sets used as model inputs for our analyses. During the simulation, LandSHIFT translates the country-level model input into spatial land use patterns. At the beginning of every time step, the suitability of each raster cell for the different land use types is determined based on the cell-level information. Thereafter, the model uses country-level data to determine and to allocate the land needed for each crop type, pasture, and settlement in the most suitable cells. The model results are raster maps that depict the spatial and temporal patterns of land use change until 2030 in 5-year time steps. Grid-level information on crop yields in the base year that are required for the spatial allocation of cropland is determined by the LPJmL model (Bondeau et al., 2007). In course of the scenario simulations, these values are adjusted according to the country-level information on crop-specific yield changes provided by the crop modeling component of the IMPACT model.

MODEL INITIALIZATION

Land SHIFT is initialized with a gridded land use map representing the year 2005. This base map is produced by merging of land-cover data from the GlobCover 2009 data set with data on the physical extent of different crop types and permanent meadows and pastures from the UN Food and Agricultural Organization FAO (ESA, 2010; FAO, 2017a). In contrast to the land-cover data set, the base map distinguishes 12 different crop types and includes a spatial allocation of pastureland. The information on the relative share of the various crop types in the total cropland area per country is derived from the input data on harvested area on country-level for the year 2005 from IMPACT. The conversion from harvested area of a crop, as specified by IMPACT, to its physical area allocated in the base map is done on a per-country basis and is kept constant for the simulation period. For this purpose, harvested area is multiplied by the ratio of total physical cropland area (FAO) over total harvested area of all crops (as derived from IMPACT). Hence, LandSHIFT assumes the same cropping intensity for all crop groups in a country, which is a clear simplification of our modeling approach as intensities may vary between cropping systems. In this study, all cropping systems have an intensity factor of 0.63, which is kept constant during the simulation period. For pasture, initialization data, that is, livestock numbers and permanent area of meadows and pasture, are taken from FAO. Table S3 shows the mapping of the GlobCover 2009 land-cover types to the land use types in the LandSHIFT model and the area that they occupy in the base map. An important outcome from the data merging process is that the cropland area depicted in GlobCover 2009 strongly exceeds the physical cropland area given in the statistical data. As a consequence, excess cropland cells are classified as set-aside in the base map. To further specify the actual land use, we overlay the base map with a regional land-cover product (Roy et al., 2015) at a spatial resolution of 30 m × 30 m and calculated the mean fraction of different land-cover types within the 5-arcmin cells. As a result of this GIS analysis, we characterize these cells as a mosaic of less intensive subsistence farming with higher field margin vegetation and/or agroforestry (20%) and fallow land/natural vegetation, especially lightly used forests and secondary forests (80%).

LAND USING PATTERN IN INDIA

1. Agriculture Agriculture is the main occupation of rural people in india district. There is 2,44,595 too small farmers and they acquired 1,04,373 hectares of land and there is small land and there is 85,021 small farmers and they are having 1,17,879 hectares of land and there is 41,426 big farmers and they acquired 1,38,573 hectares of land. India district gets 600- 1000 M.M rain fall in each year.

2. Horticulture Mango, banana, coconut and vegetables are main horticulture crops in India district. The coconut got 19404 hectares of land, banana got 1570 hectares of land and vegetables got 4431 hectares of land in India . Horticulture also got much importance in inclusive growth of india district. The physical requirement was about 44701 lakhs in 2007-08 and it is increased about 1,38,310lakhs in 2011-12. Like that the financial requirement for the development of horticulture was about 0.45 lakhs and its increased by 335.03 lakhs in 2011-12.

3. Sericulture There is 2049.69 hectares of land is underutilization of sericulture in India district. Sericulture got less importance than other activities but still its importance increasing slowly. The physical requirement was about 89 lakhs in 2007-08 and it is increased by 141 lakhs in 2011-12 like that the financial requirements for sericulture development was about 0.09 lakhs in 2007-08 and it has increased about 0.74 lakhs in 2011-12.

4. Animal husbandry Animal husbandry is one of the main occupation of the farmers of rural areas in India district. There is 18 hospitals, 64 medical centres, 74 primary veterinary health centres 7 mobile medical centres and 629 milk producers co-operatives in district. Animal husbandry also got a huge importance in India district. The physical requirement was about 17195 lakhs and financial requirement about 0.17 lakhs in 2007-08 and these standings increased about 25714 lakhs and 153.35 lakhs respectively in 2011-12.

5. Watershed development Proper utilization and protection of land, water, animals and human resources which are in watershed lands it is called watershed development. This watershed development also got some importance in India district. The physical requirement and financial requirement was about 2440 and 0.02 lakhs respectively in 2011-12 for the watershed development in India district. The land use land cover within an area is varied with the knowledge of the present land use pattern the issue of solid waste management would be successfully studied. Every land use type produces different kind of solid waste. The category and quantity of solid waste of that area is caused by the resultant of the change in land use and land cover.

ASSESSMENT OF IMPACTS ON BIODIVERSITY

We use the Biodiversity Intactness Index (BII) for quantifying the impact of land use change on biodiversity. The BII is an indicator of the average abundance of a large and diverse set of organisms in a given geographical area, relative to reference populations in the preindustrial period (Scholes & Biggs, 2005). The BII was originally developed for analyses in Southern Africa (e.g., Biggs et al., 2008). In recent publications related to the Planetary Boundary concept, it has been proposed as a suitable indicator to measure the loss of species diversity in large-scale assessments (Steffen et al., 2015) and applied for continental and global analyses (Koch et al., 2019; Newbold et al., 2016). Calculations of the BII are carried out for the land use maps generated by Land SHIFT. Here, each cell represents an ecosystem with its areal extent being the cell size and its species richness described by the sum of bird, mammal, and amphibian species. Spatially explicit data on species richness is derived from the global data set by Jenkins et al. (2013). The BII at the country-level is determined by summing up the individual grid cell values.

IMPACTS OF LAND USE CHANGE ON BIODIVERSITY

The BII for India in the year 2010 is 41.67%. Changes of BII in our scenarios are driven by the conversion of natural and set-aside land to cropland, pasture, and urban area as well as by the intensification of cropland and pasture. Figure 5a gives an overview of BII changes due to these impacts. The impacts of the expansion of agricultural and urban land on the BII are relatively small across all scenarios. Under REF_NoCC, the scenario with the lowest expansion of agricultural area, the BII decreases by 1.01%, followed by the REF_HGEM scenario with a decrease of 1.13%. The two investment scenarios show significantly higher expansion rates, especially of pasture, into set-aside areas leading to larger decreases of the BII (MED: −1.19%; HIGH+RE: −1.29%).

Moreover, due to the different assumptions regarding agricultural intensification, there are further decreases of the BII across all scenarios. Increases in crop yields are assumed to be realized e.g. with high productive crop varieties and improved nutrient and soil management (see section 2.5) whereas increasing livestock density results in higher pressures on grassland ecosystems. Due to its high fraction of intensive cropland and man-made pastures, the strongest decrease of BII due to agricultural intensification can be found in the HIGH+RE scenario with −4.48%. In contrast, the REF_NoCC scenario shows the lowest decrease of BII by −3.14% and is characterized (together with REF_HGEM) by the smallest fraction of intensive cropland and man-made pasture. Summarizing the effect of both processes, we see that the HIGH+RE scenario exerts the highest pressure on species abundance of amphibians, birds, and mammals for the year 2030 in India with the BII decreasing to 35.9%.

IMPACTS OF LAND USE CHANGE ON CARBON STORAGE

Similar to the biodiversity losses, carbon stock changes are driven both by processes of land conversion, such as conversion from forest to agriculture, and by the intensification of agricultural management. As shown in Figure 5b, the calculated annual CO2 emissions have negative values under all scenarios representing a net uptake of CO2 from the atmosphere. As a result, soil carbon stocks are increasing. The REF_HGEM scenario shows the lowest annual uptake of CO2 (−35.42 MtCO2/a), followed by the REF_NoCC scenario (−46.35 MtCO2/a). As the assumptions regarding increases in agricultural management and livestock grazing in both scenarios were similar, differences in CO2 uptake can be attributed to the different expansion rates of agricultural land. In the REF_HGEM scenario, more set-aside land with relatively high carbon stocks in vegetation and soil are converted to cropland and pasture due to depressed yields under climate change conditions. Under the investment scenarios, the additional improvements of agricultural management, including reduced tillage practices, have a significantly positive effect on the rates of CO2 uptake. Under the MED scenario, the annual uptake is 92.93 MtCO2/a while the HIGH+RE increases this to 246.76 MtCO2/a. In summary, under our scenario assumptions regarding the improvements in agricultural management practices on cropland, we calculate a strong uptake of carbon from the atmosphere. As this uptake is higher than carbon losses due to the conversion of set-aside and natural land, we find a net carbon sink in agricultural soils.

CONCLUSION

Socio-economic factors, such as population and economic growth, are main drivers for increasing future food demands in India. Under the different scenarios modeled here, the projected crop production growth ranges from 43% to 55% between 2010 and 2030. At the same time, livestock production is projected to more than double. These results are supported by the findings of other studies, like the "Vision 2050" done by the Indian Council of Agricultural Research (ICAR, 2015). Food provision in India will face problems similar to those in China, the other major player in Asia in that significant change of agricultural policies and management practices are required to realize the necessary production increases in a more sustainable way (Yu & Wu, 2018). Our results also highlight that climate change affects Indian food supply in a negative manner and that higher future R&D investments in the agricultural sector can trigger food production increases that will offset these losses in productivity. To meet the future crop production demands and SDG 2 (Zero Hunger), our study shows that, in India, crop yields must increase and cultivated lands must expand. In addition, the huge increases in demand for animal products require additional pastureland. The results suggest that most conversions to cropland and pasture take place on set-aside land that, according to our GIS-analysis, consists of a mosaic of extensive farming and remaining natural vegetation (Roy et al., 2015; Tian et al., 2014).

REFERENCES

Agrawal, A., Pandey, R. S., & Sharma, B. (2010).Water pollution with special reference to pesticide contamination in India.Journal of Water Resource and Protection, 2(05), 432.

Alexander, P., Prestele, R., Verburg, P. H., Arneth, A., Baranzelli, C., Batista e Silva, F., et al. (2017). Assessing uncertainties in land cover projections. Global Change Biology, 23(2), 767–781. https://doi.org/10.1111/gcb.13447

Alexandratos, N., &Bruinsma, J. (2012). World agriculture towards 2030/2050: The 2012 revision (ESA Working Papers). ESA Working Paper No. 12-03, Agricultural Development Economics Division, Food and Agriculture Organization of the United Nations. Rome.

Alkemade, R., Reid, R. S., van den Berg, M., de Leeuw, J., &Jeuken, M. (2013). Assessing the impacts of livestock production on biodiversity in rangeland ecosystems. Proceedings of the National Academy of Sciences of the United States of America, 110(52), 20900–20905. https:// doi.org/10.1073/pnas.1011013108

Alkemade, R., Van Oorschot, M., Miles, L., Nellemann, C., Bakkenes, M., & Ten Brink, B. (2009). GLOBIO3: A framework to investigate options for reducing global terrestrial biodiversity loss. Ecosystems, 12(3), 374–390. https://doi.org/10.1007/s10021-009-9229-5

Arneth, A., Sitch, S., Pongratz, J., Stocker, B. D., Ciais, P., Poulter, B., et al. (2017). Historical carbon dioxide emissions caused by land-use changes are possibly larger than assumed. Nature Geoscience, 10(2), 79–84. https://doi.org/10.1038/ngeo2882

Bhagowati, B., &Ahamad, K. U. (2018). A review on lake eutrophication dynamics and recent developments in lake modeling. Ecohydrology& Hydrobiology.

Bhattacharyya, R., Ghosh, B., Mishra, P., Mandal, B., Rao, C., Sarkar, D., et al. (2015). Soil degradation in India: Challenges and potential solutions. Sustainability, 7(4), 3528–3570. https://doi.org/10.3390/su7043528

Biggs, R., Simons, H., Bakkenes, M., Scholes, R. J., Eickhout, B., van Vuuren, D., &Alkemade, R. (2008).Scenarios of biodiversity loss in southern Africa in the 21st century. Global Environmental Change, 18(2), 296–309. https://doi.org/10.1016/j.gloenvcha.2008.02.001

Bondeau, A., Smith, P. C., Zaehle, S., Schaphoff, S., Lucht, W., Cramer, W., et al. (2007). Modelling the role of agriculture for the 20th century global terrestrial carbon balance. Global Change Biology, 13(3), 679–706. https://doi.org/10.1111/j.1365-2486.2006.01305.x

Brahmanand, P. S., Kumar, A., Ghosh, S., Chowdhury, S. R., Singandhupe, R. B., Singh, R., et al. (2013).Challenges to food security in India. Current Science, 841–846.

Brooker, R. W., Karley, A. J., Newton, A. C., Pakeman, R. J., &Schöb, C. (2016). Facilitation and sustainable agriculture: A mechanistic approach to reconciling crop production and conservation. Functional Ecology, 30(1), 98–107. https://doi.org/10.1111/1365-2435.12496

Chand, R., &Parappurathu, S. (2012). Temporal and spatial variations in agricultural growth and its determinants. Economic and Political Weekly, 47(26–27), 55–64. https://doi.org/10.1016/B978-0-12-088782-8.50006-1